Introduction

Information technology (IT) is a manifestation of public and private investment in science and engineering (S&E) that is enabling broad and significant changes in society. Many observers (Drucker 1999; Alberts and Papp 1997; Castells 1996; Freeman, Soete, and Efendioglu 1995; Kranzberg 1989) compare the rapid development and expansion of IT to the industrial revolution in terms of its potential scope and impact on society. Few other modern advances in technology have had the capacity to affect so fundamentally the way people work, live, learn, and govern themselves. As with the industrial revolution, both the time and direction of many of the changes are difficult to predict.

The relationship between IT and S&E has two aspects. In addition to being a product of S&E, IT is enabling changes in S&E. IT has become an important part of the overall U.S. investment in research and development (R&D) and affects how R&D is conducted in all disciplines. For example, scientists and engineers make extensive use of computer modeling and simulation and large shared databases; advances in networking facilitate global collaboration in research and product development; and IT producers employ scientists and engineers, implement the results of academic research, and conduct significant amounts of applied R&D. IT also influences the pipeline for S&E through its effects on the demand for people with technical skills and through its use in education at all levels.

This chapter addresses IT as a leading example of the effects of investment in S&E on society and focuses on IT as a major force underlying changes in the S&E enterprise.

A complete discussion of the impact of IT on society and the economy is beyond the scope of this chapter because IT has become integrated into nearly all aspects of society, from entertainment to national security. Moreover, in recent years, other government publications (Council of Economic Advisers 2001; U.S. Department of Commerce (DOC) 2000a,b) have begun to cover important aspects of the digital economy. References and notes in this chapter direct the reader to some of these other more detailed sources.

The chapter begins with a description of trends in IT and then discusses some major implications of IT, including effects on the economy and the general public. Finally, it discusses the effects of IT on elements of the S&E system, including R&D, innovation processes, higher education, and the IT workforce.

Trends in IT

IT, as defined in this chapter, reflects the combination of three key technologies: digital computing, data storage, and the ability to transmit digital signals through telecommunications networks. Rapid changes in semiconductor technology, information storage, and networking, combined with advances in software, have enabled new applications, cost reductions, and the widespread diffusion of IT. The expanding array of applications makes IT more useful and further fuels the expansion of IT.

Semiconductor Technology

Enormous improvements in the performance of integrated circuits and cost reductions brought about by rapid miniaturization have driven much of the advances in IT. See sidebar, "Moore's Law."

A related trend is the migration of computing into other devices and equipment. This is not a new trend—automobiles have been major users of microprocessors since the late 1970s—but as semiconductor chips become more powerful and less expensive, they are becoming increasingly ubiquitous. Also, new capabilities are being added to chips. These include microelectromechanical systems (MEMs), such as sensors and actuators, and digital signal processors that enable cost reductions and extend IT into new types of devices.[1] Examples of MEM devices include ink-jet printer cartridges, hard disk drive heads, accelerometers that deploy car airbags, and chemical and environmental sensors (Gulliksen 2000). Trends toward improvements in microelectronics and MEMs are expected to continue. See sidebar, "Nanoscale Electronics."

Information Storage

Disk drives and other forms of information storage reflect similar improvements in cost and performance. (See figure 8-2.) As a consequence, the amount of information in digital form has expanded greatly. Estimates of the amount of original information (excluding copies and reproductions) suggest that information on disk drives now constitutes the majority of information (Lyman and Varian 2000). (See appendix table 8-2.) Increasingly, much of this information is available on-line.

Computers, reflecting the improvements in their components, have shown similar dramatic improvements in performance. Due to improvements in semiconductors, storage, and other components, price declines in computers (adjusted for quality) have actually accelerated since 1995. (See figure 8-3.)

Networking

The third trend is the growth of networks. Computers are increasingly connected in networks, including local area networks and wide area networks. Many early commercial computer networks, such as those used by automated teller machines and airline reservation systems, used proprietary systems that required specialized software or hardware (or both). Increasingly, organizations are using open-standard, Internet-based systems for networks.[2] As people have been

[1] Related terms are microstructure technologies or microsystem technologies (MSTs). To some, MSTs include all chips that have noncomputing functions (such as sensors or actuators), whereas MEMs are the subset of MSTs that have moving parts (Gulliksen 2000).

[2] The Internet, as defined by the Federal Networking Council, refers to the global information system that "(i) is logically linked together by a globally unique address space based on the Internet Protocol (IP) or its subsequent extensions/follow-ons; (ii) is able to support communications using the Transmission Control Protocol/Internet Protocol (TCP/IP) suite or its subsequent extensions/follow-ons and/or other IP-compatible protocols; and (iii) provides, uses, or makes accessible—either publicly or privately—high level services layered on the communications and related infrastructure described herein" (Kahn and Cerf 1999).